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SOUR SAWDUST AND BARK
ITS ORIGIN, PROPERTIES, AND EFFECT ON PLANTS

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE
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INTRODUCTION

Large amounts of sawdust from the Pacific Northwest lumber industry are used as horticultural mulch, providing a market for a product that not long ago posed a disposal problem. Ground bark is now also in demand by horticulturists and home gardeners. Bark also is subject to many of the changes applicable to sawdust, and the information presented in this paper is pertinent to processors and users of either material.

Partially rotted sawdust is generally preferred for horticultural use over fresh material because of its more pleasing dark color and its lower demand for nitrogen. Most horticultural sawdust is highly beneficial to plant growth (Allison and Anderson 1951, Shutak and Christopher 1952, Dunn, Macdonald, and Baker 1952, Lunt 1955, Anderson 1957, Bollen and Glennie 1961). However, some darkened sawdust is strongly acid and produces fumes toxic to vegetation (Bollen and Lu 1966).

Sawdust is usually stored in large piles (fig. 1). Under such conditions, moist sawdust may become compacted to the extent that air is excluded from the center of the pile. In the absence of free oxygen, anaerobic micro-organisms generate various organic acids and produce heat (Carlyle and Norman 1941, James and Lejeune 1952).

Figure 1.—Sawdust storage pile with sour center. Source of samples 1 and 4.

As heating of the interior of the sawdust pile increases, thermophilic microbes add to the total energy conversion until temperatures become high enough to inactivate all microbial life. Heating is further increased by interaction of the chemical products and autooxidative processes, often leading to charring, if not spontaneous combustion, in large piles. Temperatures as high as 900° F. have been recorded in fermenting wood chips (Chalk 1968), and serious economic losses of this material are suffered (Chalk 1968, Shields 1967). Piles of chunk or ground tree bark, moist hay or grain, compost piles, and manure heaps are all subject to such heating during fermentation.

In piles of finely divided wood fibers, including sawdust, wood in the highly heated portion of the pile undergoes charring and destructive distillation. This process produces pyroligneous acid which, in turn, contains acetic acid and lesser amounts of other fatty acids, methanol, formaldehyde, ketones, phenols, and other compounds which can be harmful to plant life (Hawley 1946). These decomposition products produce a persistent acrid odor to the charred material and to that of surrounding areas of the pile. The microbial generation of organic acids is often so intense that the emitted acrid vapors can be overwhelming.

Such odors arising from sawdust should be ample warning of its unsuitability for application near plants. Injury or killing of shrubs and young fruit trees has been observed after the plants were mulched with fermented sawdust. Our study sought the reasons for the ill effects of sour sawdust on plant growth and suggests simple tests that gardeners and horticulturists can use to determine for themselves if a particular lot of sawdust is safe to use.

ANALYSES OF SOUR SAWDUST

Methods

Preliminary tests were made on black Douglas-fir sawdust taken from several gardens and lawns where damage to plants followed almost immediately after application. Acrid odors and strong acidity (pH 1.9-2.2) were found.

Samples of Douglas-fir sawdust representing the following conditions were then collected in sterile, 1-gallon screwcapped jars:

1. Sour sawdust from the fermented center of a large pile (figs. 1 and 2).
2. Sour sawdust from a second pile.
3. Sour sawdust from a third pile.
4. Dark brown sawdust immediately above the fermented center of pile No. 1.
5. Light-colored weathered sawdust from the edge of a pile stored in an orchard for 2 years.
6. Fresh sawdust collected directly under a gang saw operating on cants from ponded logs.

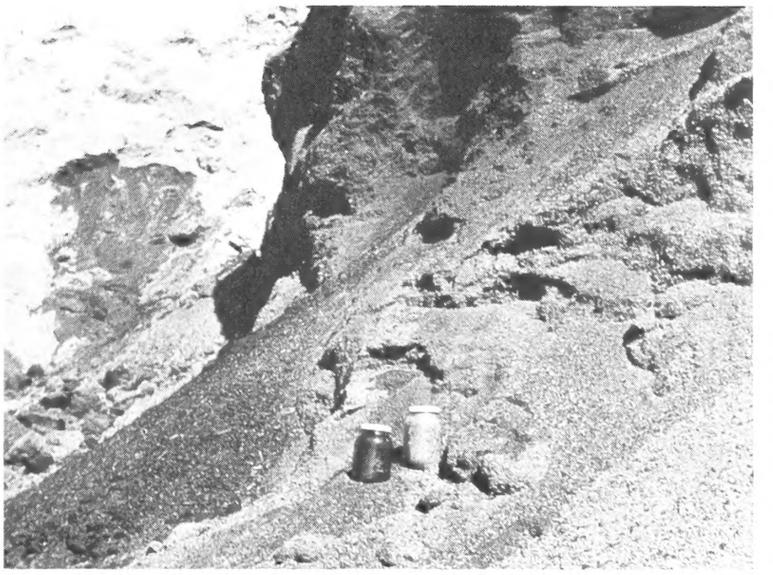

Figure 2.—Closeup of sour sawdust in center of pile shown in figure 1. Note black appearance of sample 1 in jar; contrast with light color of "normal" sawdust from surface of pile shown in upper left. Dark area in "normal" pile shows exposed, wet sawdust below surface.

All samples were screened through a 10-mesh sieve and placed in screwcapped 1-gallon jars. Titratable acidity, pH, and lime requirement determinations were made on the samples as received. For ash, carbon, and nitrogen analyses, subsamples were air-dried and hammermilled to pass a 60-mesh sieve. All samples were weighed on an ovendry basis, and results are so expressed.

Data were obtained by the following procedures:

Water content--by drying at 105° C. for 24 hours.
Ash--burning in a muffle furnace at 700° C.
Nitrogen--Kjeldahl method.
Carbon--dry combustion at 1,400° C. (Allison, Bollen, and Moodie 1965).
pH--on 1:10 mechanically stirred water suspensions of 10-mesh[1/] material after 1 hour preliminary stirring, using the glass electrode with a Beckman[2/] automatic titrator.

The results are shown in table 1.

In addition to the foregoing properties, total acidity was determined by titration with 0.1 NaOH of 10-gram samples in 100 milliliter water while stirring 1 hour on the Beckman automatic titrator. The first titration was made after the 1:10 suspensions stood 24 hours with occasional stirring. The titration was extended to 48 hours and to 7 days. Results are given on a cumulative basis and expressed as pounds of limestone ($CaCO_3$) required to neutralize 1 ton (dry basis) of sawdust (table 2). The end point of pH 8.35 was chosen because this is the value at which carbonates are converted to bicarbonates, also, it is near the neutralization point of phenolphthalein which is commonly used as an indicator for titration of weak acids with strong bases. Acidity of water extracts (table 3) and effect of Added $CaCO_3$ on pH (table 4) were determined in similar manner.

1/ All of sample passing a 10-mesh sieve.
2/ Mention of products by name does not constitute endorsement by the U.S. Department of Agriculture.

Table 1.--*Analysis of sour and other Douglas-fir sawdust*

Sample number	pH	Lime requirement	Ash	Total carbon	Kjeldahl N	C/N ratio
		Pounds $CaCO_3$ per ton	*Percent*	*Percent*	*Percent*	
1 Sour[1/]	2.2	292	1.90	53.26	0.07	761
2 Sour[1/]	2.2	300	.93	53.60	.06	893
3 Sour[1/]	2.1	295	1.03	56.25	.08	703
4 Dark brown[2/]	2.5	69	1.10	49.33	.11	448
5 Weathered[3/]	4.0	8	.41	49.49	.04	1,237
6 Fresh[4/]	4.0	8	.39	50.30	.04	1,258

[1/] Samples of sour sawdust from spontaneously heated and partially charred centers of different piles.

[2/] Sample of dark brown, not charred, sawdust taken near heated and charred area.

[3/] Sample from edge of shallow pile weathered 2 years.

[4/] Sample taken directly under gang saw.

Table 2.--*Titratable acidity and pH of 1:10 water suspensions of sour, weathered, and fresh Douglas-fir sawdust*[1/]

Sample number	pH[2/]	0.1 N NaOH to titrate to pH 8.35, cumulative[3/]			Total acidity as acetic
		24 hour	48 hour	7 days	
		Milliliter	*Milliliter*	*Milliliter*	-- *Percent* --
1 Sour	2.2	261.0	278.7	291.9	17.5
4 Dark brown	2.5	58.2	61.9	68.8	4.1
5 Weathered	4.0	5.2	6.3	7.8	.5
6 Fresh	4.0	5.9	7.1	8.3	.5

[1/] 10.0 grams(ovendry basis), all of sample passing 10-mesh sieve, in 100 milliliters distilled water.

[2/] After stirring 1 hour.

[3/] During 1 hour stirring after standing for each interval. Values equivalent to pounds $CaCO_3$ required to neutralize 1 ton sawdust, ovendry basis.

Table 3.--*Titratable acidity of successive 1:5 water extracts of sour sawdust (sample 1)*[1/]

Extract number	pH	0.1 N NaOH to neutralize 100 milliliters to pH 8.35	$CaCO_3$ equivalent per ton sawdust
		Milliliters	*Pounds*
1	2.0	415	208
2	2.3	214	107
3	2.8	58	29
4	2.8	38	19
5	3.0	29	15
6	3.0	29	15
Total		783	393

[1/] 1,380-gram wet sample, equivalent to 730 gram, ovendry basis, shaken with 3 liters of cold water 10 minutes and suction filtered to apparent dryness. Repeated 5 times.

Table 4.--*Effect of $CaCO_3$ on pH of 1:10 water suspensions*

Sample number	$CaCO_3$		Duration of contact[2/]						
			0 hours[1/]	2 hours	18 hours	36 hours	60 hours	134 hours	7 days
	grams	*pounds/ton*	- - - - - - - - - - - - - - - - - - *pH* - - - - - - - - - - - - - - - - - -						
1	2.5	100	2.2	3.4	3.4	3.4	3.4	3.6	3.5
1	5	200	2.2	4.4	4.4	4.3	4.4	4.5	4.3
1	7.5	300	2.2	5.7	6.1	6.4	6.8	6.8	7.0
4	1	40	2.5	4.7	4.6	4.2	4.4	4.4	4.4
4	2.5	100	2.5	6.0	6.4	6.4	6.4	6.4	6.4
5	1	40	4.0	6.6	7.0	7.0	7.0	6.9	6.9
6	1	40	4.0	6.5	6.8	6.8	6.8	6.7	6.8

[1/] Before adding $CaCO_3$.

[2/] With intermittent stirring.

Acid identification was done by gas chromatography[3], using an F & M Scientific Corporation, Model 402 gas chromatograph with a 4-foot, 6- by 4-millimeter Pyrex U column packed with Chromsorb PAW 60-80 coated with 20 percent of Neo Pental Glycol Succinate. Chromatographs of 1:10 distilled water extracts, obtained after mechanically shaking the suspension 1 hour before filtering through a Pyrex M fitted glass filter, were made from sour and fresh sawdust. Standards were run on reagent-grade formic, acetic, propionic, butyric, and caproic acids.

Numbers of micro-organisms were determined by the dilution plate method, using peptone-glucose-acid agar (Waksman and Fred 1922) for molds, and nutrient agar and Brewer's anaerobic agar (Anonymous 1953) (with anaerobic incubation) for bacteria.

Carbon dioxide production by fresh sawdust was measured on 50-gram samples (ovendry basis) with a water content of 107 percent, as obtained from the gang saw, placed in each of three 1-pint bottles and connected to a moist, CO_2-free air supply in a 28° C. incubator. The exit air was bubbled through 1N NaOH in test tubes. At 1, 5, 8, 12, 19, and 28 days the tubes were removed and replaced with tubes of fresh alkali, and the absorbed CO_2 was determined by double titration on a Beckman automatic titrator (Bollen and Glennie 1961).

Results and Discussion

Samples 1, 2, and 3 of sour sawdust were strongly acid as shown not only by the very low pH but also especially by the total acidity expressed as lime requirement, which ranged from 292 to 300 pounds of $CaCO_3$ per ton of sawdust, dry basis, equivalent to 17.5- to 18.0-percent total acids as acetic (tables 1 and 2). A bulk sample of charred material stored in a 10-gallon tinned milk can illustrated the potency of this highly acid sawdust. Several months after collection, we tried to open the can. It was so corroded from the inside it fell apart.'

Although the dark brown sample taken above the black sample No. 1 had a pH of 2.5, compared with 2.1 to 2.2 for the sour sawdust, the total acidity was much less, only 69 pounds $CaCO_3$ equivalent per ton. This dark sawdust apparently absorbed enough volatile acid from the underlying heated sawdust to lower the pH considerably, but the total acidity was little more than one-fourth as much. Higher total carbon values (table 1) of the sour sawdusts is evidence of strong spontaneous heating, leading to loss of CO_2 and some of the volatile acids and other organic compounds.

Although much of the acidity was rapidly soluble in water, an additional 10 percent of the total was found at 7 days. Probably some additional acid would be released over a more prolonged time. This is indicated also by the acidity determined on successive water extracts (table 3). Fifty-three percent of the total acid extracted was in the first extract, 27 percent in the second extract, followed by less and less until only 3.7 percent was in the sixth extract. It is thus evident that much of the acidity is persistent; in a mulch, even under leaching by rainfall or irrigation, the toxicity would be prolonged, and the total lime requirement could reach 400 pounds per ton.

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[3] Assistance of Dr. A. W. Anderson, Professor of Microbiology, Oregon State University, in performance of the gas chromatography is gratefully acknowledged.

Many of the organisms in weathered sawdust probably represent contaminants from the soil; although in fresh sawdust, the microbes could have developed from forms contaminating the logs, from contaminants carried by air, and from other sources. Water would contribute many organisms to ponded logs. Runoff from leaf surfaces can inoculate bark of standing trees with a variety of microbes. However, bacteria and fungi are known to occur in healthy as well as in diseased plant tissue. The presence of a fungus in living tissues of conifers has been reported by Lewis (1924). Bloomberg (1966) found fungi of soil-borne and seed-borne origin in Douglas-fir roots, shoots, and seed coats, and Hudak (1964) detected micro-organisms in sound wood of western hemlock. Bacteria as well as fungi have been found in normal heartwood of sugar maple (Basham and Taylor 1965). A rod-shaped, gram-negative bacterium occurred in normal sapwood of 135 out of 229 cottonwood (*Populus deltoides*) trees sampled by Toole (1968). *Bacillus polymyxa* and other sporeforming, facultatively anaerobic bacteria have been found in freshly felled ponderosa and sugar pine trees and in great abundance in log pond water (Ellwood and Ecklund 1959). These bacteria attack hemicellulose and pectin, causing destruction of sapwood and ray cells.

Although it is thus possible that cells of wood and bark contain bacteria and fungi that have entered through wounds, stomata, or other openings, the role of such organisms in the fermentation of sawdust, chip, and bark piles would seem to be minor. It is more likely that most, if not all, of the microbes involved arise from various outside contaminations.

Naturally occurring enzymes in freshly cut wood can continue respiration for several days. Studies by Springer and Hajny (1970) indicate that heat is released from fresh, green aspen and Douglas-fir chips free of micro-organisms by action of enzymes in the living ray parenchyma cells. However, it seems unlikely that such enzymes take part in the fermentation of piled sawdust or bark because logs are not usually milled within a few days after the trees are felled.

The organisms in fresh sawdust (sample 6) from ponded logs metabolize rapidly under favorable conditions, shown by the rapid evolution of CO_2 (fig. 3). Incubated samples produced this gas at only a slightly decreasing rate during 28 days, at which time 0.44 percent of the total carbon was evolved as CO_2. Because CO_2 production releases heat, such activity in a large insulated mass could soon lead to considerable rise in temperature and consequent high acidity.

GREENHOUSE STUDIES WITH SOUR SAWDUST

Methods

Radish, sunflower, corn, and onion seeds were planted in Cloquato silt loam soil in a series of flats in one of which the soil was left bare, and the others were covered with 1-inch-deep mulches of the different sawdusts. In a second set of flats, young tomato, pepper, and cabbage plants were transplanted and mulched as for the seeded flats. All were left in the greenhouse and watered as necessary.

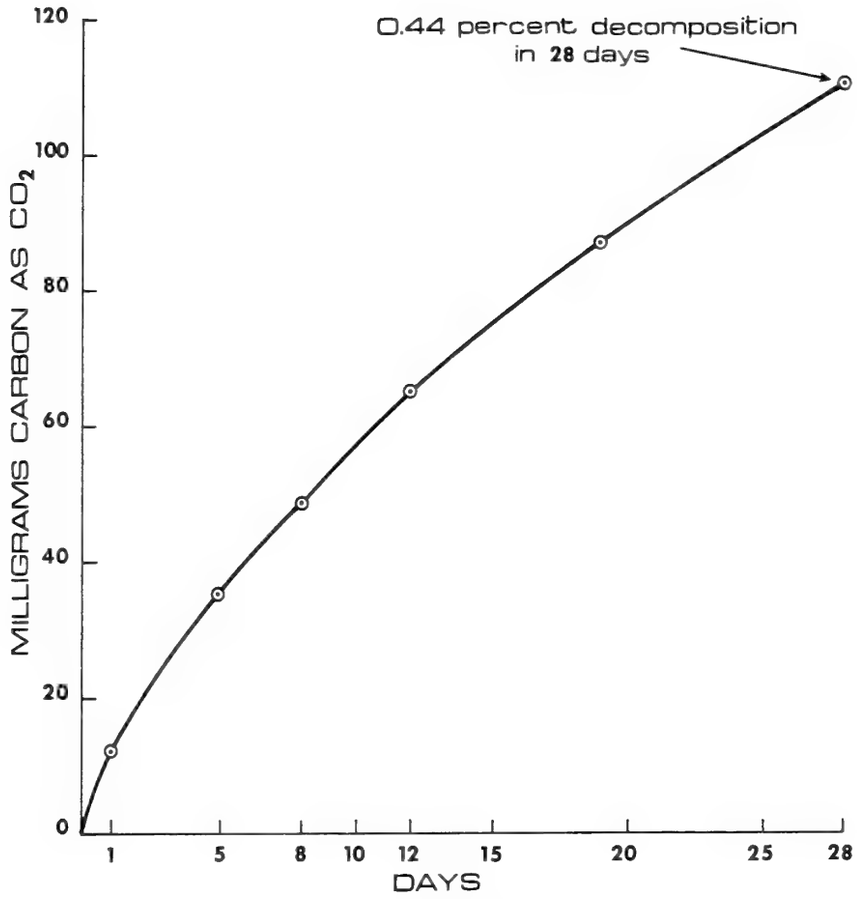

Figure 3.—Carbon dioxide evolution from fresh Douglas-fir sawdust (50 grams, ovendry basis, incubated at 28° C. with 107-percent moisture (38 percent of water-holding capacity)).

Results and Discussion

Seed germination under both weathered and fresh sawdust (samples 5 and 6, page 2) was comparable for radish, sunflower, and corn, but the plants became more or less yellow, indicating nitrogen deficiency. A light application of ammonium nitrate in solution after 28 days alleviated these symptoms. Onion seed germination under these sawdusts was much less than in the unmulched soil, but the seedling development was normal. The most striking results were with the sour sawdust (sample 1). No radish and few sunflower seeds germinated; the sunflower seedlings soon yellowed, died, and appeared bleached. Corn and onion seeds germinated well, but again, the seedlings soon died. The dark brown sawdust (sample 4), only slightly less acid than the sour sawdust, gave similar results, although sunflower germination was better (figs. 4 and 5).

The sour sawdust mulch killed and bleached the transplanted tomato, pepper, and cabbage plants within 7 days. Pepper plants grew normally under the other sawdusts. Cabbage was normal under fresh sawdust but under weathered and dark brown sawdust died within 28 days. Tomato plants under fresh, weathered, and dark brown sawdust (samples 6, 5, and 4) survived but showed nitrogen deficiency.

These results illustrate the deadly potency of sour sawdust and confirm similar results experienced in a number of home gardens. Attempts to render the sawdust safe

Figure 4.—Effect of different sawdust mulches on plant growth: (1) Leached Douglas-fir sour sawdust; (2) fresh sawdust collected directly under a gang saw operating on cants from ponded logs; (3) light-colored weathered sawdust from the edge of a pile stored in an orchard for 2 years; (4) sour sawdust from the fermented center of a large pile (figs. 1 and 2).

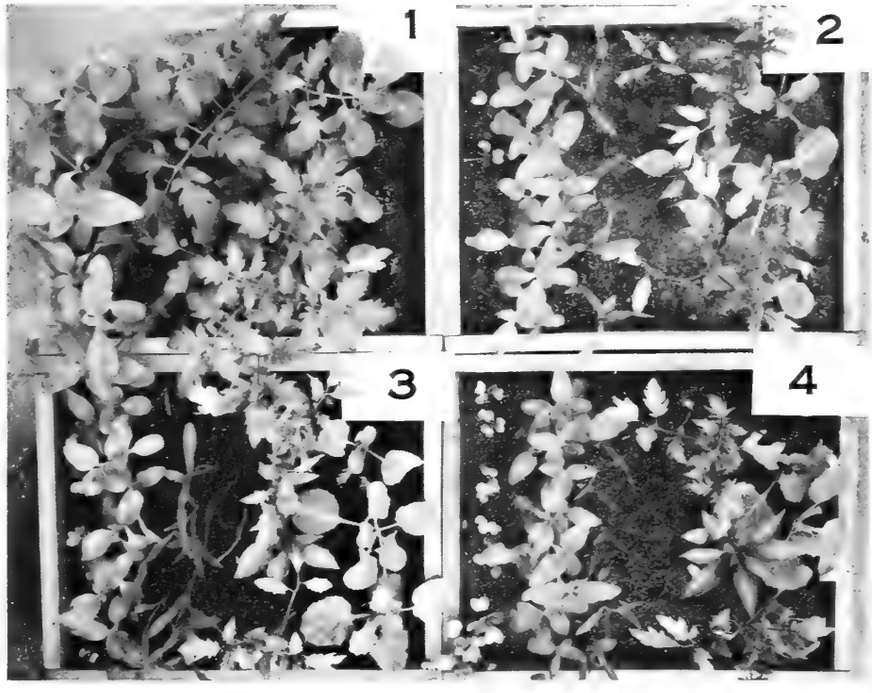

Figure 5.—Effect of different mulches on plant growth: (1) Soil only, no mulch; (2) wheat straw; (3) red alder sawdust; (4) fresh sawdust collected directly under a gang saw operating on cants from ponded logs.

by spreading it on open ground in a layer 3 to 4 inches deep for several weeks during the summer were not successful. Some of the volatiles undoubtedly were dissipated, but the sharp odor and most of the acidity remained. Copious leaching in the laboratory was effective but would be impractical for field use (table 3 and fig. 4).

Under field conditions sour sawdust around plants may injure or kill not only seedlings but also shrubs and small trees. The fumes will at least cause yellowing or bleaching of leaves and defoliation, even if below-ground parts are not harmed. In some cases recovery follows. This is generally true with lawn grass. Severity of injury is dependent upon rate of application and weather conditions. Leaching by rain or irrigation accelerates root damage, and warm air and heating by sunlight hastens evolution of fumes and rapid injury to leaves and tender plants.

Table 4 shows the amount of $CaCO_3$ required to bring water suspensions of the sawdust to neutrality. Three hundred pounds $CaCO_3$ per ton of sour sawdust, dry basis, and 7 days contact with intermittent stirring raised the pH to 7.0. For the less acid, dark brown sawdust, 1 ton would be nearly neutralized by 40 pounds of $CaCO_3$. Nevertheless, even this less acid material exhibited some toxicity in the greenhouse study.

Plate counts of micro-organisms showed that the sour and dark brown sawdusts were sterile (table 5). Dilutions as low as 1:10 showed no molds or bacteria, either aerobic or anaerobic. Also, samples of the sawdust placed directly on plates of various media gave no growth. The sterility can be attributed to the high temperature and acidity developed during the fermentation and subsequent reactions. Weathered sawdust was higher in molds but lower in bacteria than the fresh sawdust. *Trichoderma* predominated in the fresh sawdust, and *Penicillium* species comprised the other molds present. Weathered sawdust, on the other hand, contained few *Penicillium* species, no *Trichoderma*, and a majority of unidentifiable forms. Five percent of the total bacteria in weathered sawdust were *Streptomyces*, but none were found in the fresh sawdust.

Table 5.--*Bacteria and molds in fresh and sour Douglas-fir sawdust*[1/]

Sample number	Sawdust	Molds			Bacteria		
					Aerobic		Anaerobic[2/]
		Total	Penicillia	Trichoderma	Total	Streptomyces	Total
		Thousands	*Percent*	*Percent*	*Millions*	*Percent*	*Millions*
1	Sour	0	0	0	0	0	0
4	Dark brown	0	0	0	0	0	0
5	Weathered	11,400	5	0	1.8	5	.3
6	Fresh	900	23	77	3.4	0	1.9

[1/] Numbers per gram, ovendry basis.

[2/] Including facultatively anaerobic aerobes.

CONCLUSIONS

The damaging effect on plants of mulches of very dark to almost black sawdust is due largely to acetic acid and lesser amounts of other volatile organic acids. These acids result from fermentation and subsequent spontaneous heating and chemical changes that occur within large compact storage piles. Such sawdust should not be used for horticultural purposes. It cannot be economically neutralized or otherwise rendered nontoxic. Bark also can undergo fermentation and become strongly acid. It, too, should be regarded as potentially toxic if it presents a highly pungent acrid odor.

The simplest test a home gardener or horticulturist can use to determine if a very dark sawdust should not be used is to smell it. If a handful held near the nose is strongly pungent, with a penetrating, intolerable acrid odor, such sawdust will certainly injure plants.

If a simple pH test kit is available it may be used: Shake one part of sawdust with 10 parts of water, let stand a few minutes, and determine pH of the liquid. A pH below about 3.5 indicates probably unsafe material. In case of doubt, refer a sample to your Agricultural Extension Agent.

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Black sawdust resulting from fermentation and heating in compacted centers of large piles is strongly acid and injurious to shrubs and plants. Its very dark color and acrid odor should warn against use for mulching and other horticultural purposes. Bark in large, moist piles is subject to similar microbial and chemical transformations.

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